6. HYDRAULIC ANALYSES

A. GENERAL

Hydraulic analyses were conducted to identify deficiencies in the CBU's distribution system and to establish an improvement program to reinforce and expand the existing system to meet projected water demands through the year 2030. Alternative improvements were investigated to identify those most effective in meeting projected water demands. Criteria used to develop the improvement program include increasing system reliability, simplifying system operations, more effectively utilizing system storage to meet peak demands, and maintaining pressures of 35 psi under maximum hour demand conditions. This chapter discusses the development of the hydraulic computer model and the results of the analyses performed.

B. EXISTING MODEL

A review of CBU's existing hydraulic model, identified as Basemap6, indicated the following:

- A water demand of 20 gpm was allocated to nearly every node;
- The tanks did not contribute to the system;
- The assigned pipe friction coefficient "C" values were not consistent with standard practice;
- The assigned pump curves did not match the curves from the shop drawings;
- The model was analyzed only for the maximum hour condition.

6. HYDRAULIC ANALYSES

Typically, a hydraulic model is analyzed for both the maximum day and maximum hour condition. The existing model indicated that the Monroe WTP provided water at maximum hour water use conditions. Water supply and treatment facilities are usually designed to meet maximum day water demands without system storage contribution. Usually, distribution storage provides rates to meet demands in excess of the maximum day use, such as, maximum hour and fire fighting needs.

C. MODEL DEVELOPMENT

1. Computer Software Program

Computerized hydraulic analyses provide a tool for predicting the system's hydraulic gradient pattern, pressures, and flows under a specified set of conditions. The hydraulic gradient pattern varies with the magnitude and location of system water use, the characteristics of the pipes in the distribution system, and the flows and gradients at network boundaries, such as at reservoirs and pump stations. The headloss through each pipe is a function of flow rate, pipe diameter, length, and internal roughness. The available pressure or head at any ground point in the network is the difference between the hydraulic gradient and the ground elevation.

The software program utilized for the analyses was CBU's licensed copy of WaterCAD, Version 4.5 by Haestad Methods. Running under the Windows operating system as a stand-alone program, WaterCAD provides an integrated environment for editing input data, running hydraulic simulations, and viewing results.

6. HYDRAULIC ANALYSES

2. Distribution System Piping and Facilities

CBU's computer model included about 400 junctions and 500 pipes totaling 125 miles in length. The modeled pipe length accounted for about 35 percent of the total pipe length within the CBU system. The hydraulic model contained about 100 percent of the 14-inch and larger mains, about 70 percent of the 12-inch mains, 85 percent of the 10-inch mains, 27 percent of the 8-inch mains, 7 percent of the 6-inch mains, and 2 percent of the 4-inch mains within the CBU system. Ground elevations for all of the nodes and the pipe diameters and lengths from the existing model were assumed to be correct.

The age of CBU's distribution mains range from mains newly constructed to mains installed prior to 1930. The pipe friction coefficient, "C" value, in the Hazen-Williams empirical equation for pipe flow, is representative of a pipe's hydraulic capacity. The "C" value is dependent upon a number of factors including pipe material, type of lining, pipe age, cross-sectional area, amount of tuberculation, and thickness of any calcium carbonate deposits. High "C" values indicate smooth interior surfaces. The "C" value for a new cement-lined ductile iron pipe, for example, is 130 or more; while for a 20-year-old pipe, it is typically 100. Prior to the 1950s, mains generally were not cement mortar lined. This caused tuberculation to form more quickly and lower "C" values to develop. The "C" values assigned in CBU's computer model were not consistent with standard practice and were deleted from the existing model. New "C" values were assigned to the mains as listed in Table 6-1.

6. HYDRAULIC ANALYSES

Table 6-1
Pipe Friction Coefficients ("C" Values)

Age, years	Diameter, inches	Year 2000 Friction Coefficient[a]	Year 2030 Friction Coefficient
<12	6-10	110	100
	12-18	110	100
	20-24	120	110
	36-48	120	110
13-23	6-10	100	90
	12-18	110	100
	20-24	110	100
	36-48	120	110
24-32	6-10	90	80
	12-18	100	90
	20-24	110	100
	36-48	120	110
33-42	6-10	80	70
	12-18	90	80
	20-24	100	90
	36-48	110	100
>42	6-10	60	50
	12-18	80	70
	20-24	90	80
	36-48	100	90

a. A "C" value of 130 was assigned to the 36-inch transmission main between the Monroe WTP and the South Storage Tanks.

Some of the pump curves found in CBU's model did not match the shop drawing curves, so they were adjusted accordingly. CBU's model was then modified to incorporate main improvements and system modifications that have occurred since 1999, the last time the model was updated. Thus, the modified model used was representative of the year 2001 CBU system.

6. HYDRAULIC ANALYSES

3. Water Demand Allocation

The total system maximum day and maximum hour water use for Base Year 2000 and Design Year 2030 replaced CBU's existing hydraulic model water demands and were allocated to the network nodes by service level and user class. Residential water use was allocated on an area basis by census tract, which assumes the population is distributed uniformly within the census tract. Commercial and industrial water use was assigned based on land use. Water use for the 35 largest ICI customers was allocated individually to specific nodes near the respective customer meters. The large customers' allocated water use was based on actual 2002 metered water use data. The water use for wholesale customers was allocated to the network nodes nearest the master metering points. Unaccounted-for water was allocated throughout the distribution system as a percentage of the total water use.

D. MODEL VERIFICATION

Prior to beginning the design hydraulic analyses, it was necessary to determine whether the hydraulic model is an accurate representation of the actual distribution system. To best make this assessment, a verification analysis was conducted to confirm that the computer model simulates actual system conditions with reasonable accuracy. Essentially, the verification process consists of selecting a known system condition using data collected from field testing and operation records.

Based upon pumping rates, varying tank levels, and the system water use during the selected test, water use factors in the distribution system model are adjusted so that the allocated water use correlates closely to the actual water use. The analysis is then performed, and the resulting pump station flows, pressures, and tank levels are compared with actual values from the records. If the calculated and actual values are substantially the same, the model is considered to be verified. If the values do not agree, the hydraulic model is revised and the analysis is repeated.

In this study, verification refinements were not performed because much of the data needed to perform a refined correlation analysis was not available.

E. HYDRAULIC ANALYSES

Hydraulic analyses were performed for maximum day and maximum hour conditions for Base Year 2000 and Design Year 2030 to identify distribution system deficiencies and to evaluate water treatment expansion alternative improvements. Analyses were not necessary for Design Years 2010 and 2020 since there were very little distribution system improvements required between 2000 and 2030 to meet the future water use conditions. The maximum day analyses determine the ability of the system to maintain storage facilities in a full condition. The maximum hour analyses determine the ability of the system to maintain adequate pressure during peak water use. Distribution system improvements were based on providing a system pressure of at least 40 psi under non-emergency conditions. As a goal, it is desirable to maintain a minimum pressure of 40 to 50 psi under maximum day conditions.

As discussed earlier, water use within a distribution system typically follows a 24-hour diurnal pattern, being low at night and peaking in the early morning and again in the late afternoon/early evening. It should be recognized, that each analysis represents an instantaneous condition within the distribution system, in essence a snapshot of the distribution system operation at a particular instant. In particular, the maximum day analyses are meant to represent the operation of the distribution system at a time when the instantaneous rate of water use is approximately equal to the average water use during the whole day.

6. HYDRAULIC ANALYSES

For discussion purposes, it is generally assumed that each maximum day analysis represents a point in time during the late afternoon, just prior to the start of the peak demand period. Ideally, the distribution system storage should be full or nearly full at this time of day, and the storage contribution rates should be essentially zero. It is desirable to have full system storage at this point in the day in order to ensure that there is a maximum volume of water available for meeting water use during the upcoming peak water use period. Additionally, it is desirable to have storage contribution rates at or near zero under the average day and maximum day water use conditions because the water stored in the system storage needs to be reserved for use during the peak water use period and for fighting fires.

In addition to the Base Year 2000 and Design Year 2030 analyses, a series of year 2030 maximum day analyses were conducted with water demands increased globally to 36 mgd to match three water treatment plant expansion alternatives that CBU is considering to meet future water demands. The three alternatives, designated as Alternative A, B, and C, are described as follows:

- **Alternative A.** Expand the 24 mgd Monroe WTP to a capacity of 36 mgd. This alternative would require another 30-inch raw water line to be installed from the intake to the plant and a parallel 36-inch finished water transmission main from the plant to the proposed 30-inch Southeast main that connects to the existing 36-inch main near Harrell Road and Moffat Lane. This alternative also includes the proposed 30-inch Southeast main along Harrell Road; a new Southeast pump station and tank located near Harrell and Rhorer Roads; a 36-inch main along Rhorer to Sare Road; a 24-inch North branch main along Sare Road to the existing 24-inch main in Moores Pike and a 24-inch West branch main along Rhorer Road, then north along South Rogers Street to West Country Club Drive, then west along Country Club Drive to connect to the two existing 24-inch mains at the intersection of Rockport and West Tapp Roads.

- **Alternative B.** Construct a new Dillman 12 mgd WTP expandable to 24 mgd, adjacent to the Dillman WWTP near Dillman Road and Victor Pike. Raw water would be conveyed through a 36-inch transmission main from a new intake located near the Indiana Department of Natural Resources site on Lake Monroe. From the Dillman WTP's high service pumps, finished water would be conveyed through a 36-inch transmission main into two 24-inch Central service level mains at Rockport and Tapp Roads and a 16-inch main along West Country Club Drive between Rockport Road and South Old SR 37. The capacity of the Monroe WTP would remain at 24 mgd.

- **Alternative C.** Construct a new North 12 mgd WTP expandable to 24 mgd, near Bottom Road and new State Route 37. Raw water would be conveyed through a 36-inch transmission main to the new plant. From the new North plant, finished water would be conveyed through a 36-inch transmission main to the Central service level mains near Stonemill Road and Old State Route 37. If the North plant is expanded to 24 mgd, then the 36-inch main should be extended as a 24-inch main along Walnut Street to the existing 24-inch main on 20th Street. The capacity of the Monroe WTP would remain at 24 mgd.

1. Base Year 2000

Hydraulic analyses were completed for the Base Year 2000 model to identify deficiencies in the existing distribution system. These analyses identified current and short-term deficiencies. The pumping information for maximum day and maximum hour conditions is summarized in Table 6-2 and shown on Figures 6-1 and 6-2.

Table 6-2 Base Year 2000 Hydraulic Analyses Pump Station Summary						
Pump Station	Rated Capacity		Maximum Day Analysis		Maximum Hour Analysis	
	Flow, mgd	TDH, ft	Flow, mgd	TDH, ft	Flow, mgd	TDH, ft
South-Central						
No. 1	6	140	4.35	135	2.21	141
No. 2	6	140	7.47	135	7.20	141
No. 3	6	140	7.47	135	7.20	141
No. 4	6	140	Off	-	6.05	141
No. 5	6	140	Off	-	Off	-
Gentry						
No. 1	1.44	140	Off	-	Off	-
No. 2	1.44	140	0.92	163	0.95	162
West						
No. 1	3.6	130	Off	-	2.09	116
No. 2	3.6	130	4.01	116	2.61	116
No. 3	4.1	150	Off	-	Off	-
Southwest						
No. 1	2	105	Off	-	Off	-
No. 2	2	105	Off	-	Off	-
No. 3	2	105	Off	-	Off	-

6. HYDRAULIC ANALYSES

Fig 6-1 2000 MD

6. HYDRAULIC ANALYSES

Fig 6-2 2000 MH

The tank information for Base Year 2000 maximum day and maximum hour conditions is summarized in Table 6-3 and shown on Figures 6-1 and 6-2.

Table 6-3
Base Year 2000 Hydraulic Analyses
Tank Summary

Tank	Calculated Hydraulic Gradient, ft		Initial Level, ft		Status		Inflow[b], mgd	
	MD	MH	MD	MH	MD	MH	MD	MH
Monroe Finished Water Reservoir	770	770	30	30	Draining	Draining	-20.45	-24.01
South Tank[a]	850	850	30	30	Filling	Filling	0.03	0.03
Red Bud	955	951	67	63	Draining	Draining	-1.47	-1.77
East	955	951	79	75	Filling	Filling	1.46	1.76
Dyer	926	926	50	50	Draining	Steady	-0.01	0.00
Southwest	1,029	1,025	83	79	Draining	Draining	-1.42	-1.66
West	1,029	1,025	92	88	Filling	Filling	1.43	1.68

a. For simplicity, the 1.0 MG and 3.0 MG South Tanks were modeled as one 4.0 MG tank.

b. Negative value indicates the tank is draining, while a positive value indicates the tank is filling.

In the Central service level, the East and Redbud tanks operate at the same hydraulic gradient elevation and fill and drain at approximately the same rate for MD and MH conditions, respectively. The East tank will overflow before the Redbud tank is replenished. To allow the Redbud tank to replenish, an altitude valve should be installed on the East tank.

6. HYDRAULIC ANALYSES

In the West service level, the West and Southwest tanks operate at the same hydraulic gradient elevation. For MD and MH conditions, the West and Southwest tanks are draining and filling at approximately the same rate, respectively. The West pump station fills the West tank, while the Southwest pump station is off-line and the Southwest tank supplies water to the West service level.

The existing distribution system is capable of meeting current maximum day and maximum hour water use conditions.

2. Design Year 2030

Analyses for Design Year 2030 were performed using the projected water use requirements presented in Chapter 3. The projected 2030 maximum day and maximum hour water use is 32.2 mgd and 38.1 mgd, respectively. The pumping information for Design Year 2030 maximum day and maximum hour conditions is summarized in Table 6-4 and shown on Figures 6-3 and 6-4.

6. HYDRAULIC ANALYSES

Table 6-4
Design Year 2030 Hydraulic Analyses
Pump Station Summary

Pump Station	Rated Capacity		Maximum Day Analysis		Maximum Hour Analysis	
	Flow, mgd	TDH, ft	Flow, mgd	TDH, ft	Flow, mgd	TDH, ft
South-Central						
No. 1	6	140	7.87	125	4.30	119
No. 2	6	140	7.87	125	8.14	119
No. 3	6	140	Off	-	8.14	119
No. 4	6	140	Off	-	Off	-
No. 5	6	140	Off	-	Off	-
Southeast						
No. 1			5.36	154	6.35	130
No. 2			5.35	154	6.35	130
No. 3			5.35	154	Off	-
No. 4			Off	-	Off	-
No. 5			Off	-	Off	-
Gentry						
No. 1	1.44	140	Off	-	Off	-
No. 2	1.44	140	0.96	162	1.00	161
West						
No. 1	3.6	130	2.19	107	2.41	99
No. 2	3.6	130	Off	-	Off	-
No. 3	4.1	150	Off	-	Off	-
Southwest						
No. 1	2	105	Off	-	Off	-
No. 2	2	105	3.55	69	3.51	70
No. 3	2	105	Off	-	Off	-

6. HYDRAULIC ANALYSES

Fig 6-3

Figure 6-4

6. HYDRAULIC ANALYSES

The tank information for Design Year 2030 maximum day and maximum hour conditions is summarized in Table 6-5 and shown on Figures 6-3 and 6-4.

Table 6-5
Design Year 2030 Hydraulic Analyses
Tank Summary

Tank	Calculated Hydraulic Gradient, ft		Initial Level, ft		Status		Inflow[b], mgd	
	MD	MH	MD	MH	MD	MH	MD	MH
Monroe Finished Water Reservoir	770	770	30	30	Draining	Draining	-31.77	-31.98
South[a]	850	850	30	30	Draining	Draining	-0.62	-5.55
Southeast	850	850	50	50	Draining	Filling	-0.29	3.04
Red Bud	955	946	67	58	Draining	Draining	-0.85	-3.07
East	955	946	79	70	Filling	Filling	1.89	1.20
Dyer	926	926	50	50	Draining	Draining	-0.004	-0.004
Southwest	1,029	1,020	83	74	Filling	Filling	1.04	0.63
West	1,029	1,020	92	83	Draining	Draining	-1.19	-1.62

a. For simplicity, the 1.0 MG and 3.0 MG South Tanks were modeled as one 4.0 MG tank.

b. Negative value indicates the tank is draining, while a positive value indicates the tank is filling.

In the Central service level, the East and Redbud tanks operate at the same hydraulic gradient elevation and fill and drain at approximately the same rate for MD conditions, respectively. For MH conditions, however, this appears to not be case. The East and Redbud tanks fill and drain at different rates. The East tank will overflow before the Redbud tank is replenished. To allow the Redbud tank to replenish, an altitude valve should be installed on the East tank.

In the West service level, the West and Southwest tanks operate at the same hydraulic gradient elevation. For MD conditions, the West and Southwest tanks drain and fill at approximately the same rate, respectively. For MH conditions, however, this appears to not be the case. The West and Southwest tanks drain and fill at different rates. The Southwest pump station fills the Southwest tank, while both the West pump station and West tank supplies water to the West service level.

Improvements between years 2000 and 2030 are needed to serve new development areas and to improve hydraulic conditions in the system.

Three additional Design Year 2030 maximum day analyses were conducted with the demand increased to 36 mgd to evaluate the WTP expansion alternatives. Results of these analyses are shown on Figures 6-5, 6-6, and 6-7. For Alternative A, the results indicate that the East tank will overflow before the Redbud tank is replenished. To allow the Redbud tank to replenish, an altitude valve should be installed on the East tank. For Alternative B, an altitude valve is not required on either the East or Redbud tanks. For Alternative C, Redbud tank will overflow before the East tank is replenished. To allow the East tank to replenish, an altitude valve should be installed on the Redbud tank. Overall, the results indicate that with the improvements described for each alternative, in place, the distribution system will be able to accommodate 36 mgd.

Fig 6-5 2030 MD alt A

Fig 6-6 2030 MD alt b

Fig 6-7 2030 MD Alt C

6. HYDRAULIC ANALYSES

F. SYSTEM STORAGE EVALUATION

Storage facilities in a distribution system serve a number of purposes, including flow equalization, fire reserve, and emergency supply. Without storage facilities, the supply, treatment, pumping, and transmission facilities would have to be sized to meet instantaneous peak water use within the service area. Designing a water system in this manner would be impractical and uneconomical. However, by constructing appropriately sized reservoirs at strategic locations throughout the service area, the required capacity of the other major system components can be reduced.

The amount of equalization storage needed is a function of an area's demand characteristics and the capacities of the major system components. It is generally most economical to size supply, treatment, pumping, and transmission facilities to meet maximum day water use and to provide equalizing storage to meet water use in excess of this rate. Thus, on a day of maximum water use, storage facilities will generally contribute water when water use is greater than the daily rate and will fill when water use is less than the daily rate.

Typically, a water utility provides sufficient fire storage to meet the fire flow requirements established by the Insurance Services Office. Each storage facility should have sufficient capacity to meet fire flow requirements within an area of influence. The influence area is a function of the distribution network and water use patterns.

Emergency storage is used in the event that regular service is disrupted by main breaks, equipment failures, power outages, raw water supply contamination, or natural disasters. The amount of emergency storage included within a particular water system is the utility's option based on an assessment of risk and the desired degree of reliability. Unlike equalization and fire storage, which should be available at all reservoir sites, emergency storage may be included at only a few sites.

6. HYDRAULIC ANALYSES

1. Equalization Storage

Equalization storage should be adequate to supply the maximum hour rate in excess of the maximum day rate for at least a 6-hour peak period. For CBU's design demand ratios, this equates to 1.5-MG of Equalization Storage or about 5 percent of the maximum day use. On a maximum demand day, storage facilities will generally contribute water when demands are greater than the instantaneous average daily rate, and will refill when demands are less than the instantaneous average daily rate.

2. Fire Storage

Fire storage is based on supplying fire flow for required durations. The Insurance Services Office (ISO) grades municipal fire defense capabilities for insurance rating purposes. The 1980 ISO Fire Suppression Rating Schedule considers three areas of evaluation: Receiving and Handling Fire Alarms, Fire Department, and Water Supply.

Part of an ISO evaluation consists of determining needed and available fire flows at various locations throughout a water utility. The needed fire flow is calculated based on the size, construction, occupancy, and exposure of each building or complex. Needed fire flows can range from 500 to 12,000 gpm. A flow of 1,000 gpm is generally sufficient for fighting fires in residential structures no higher than two stories if they are more than 10 feet apart. The fire flow is required for a specified duration, generally 2 to 3 hours, at a residual pressure of 20 psi. The system should be capable of supplying the required fire flow during the maximum day demand conditions.

For insurance rating purposes, 3,500 gpm for a 3-hour duration is the maximum fire flow required to be supplied by a municipal water system. This rate would require a Fire Storage of 0.63 MG. Fire flow requirements in excess of

3,500 gpm that cannot be met by the water system may affect the rating of the individual building. However, the overall municipal rating will not be affected.

3. Emergency Storage

Emergency storage provides a reserve supply source in the event that the water supply is disrupted by water main breaks, equipment failures, power outages, or natural disasters. The amount of emergency storage required is a CBU policy issue, considering the risk of supply disruption and the desired degree of reliability. The volume required to meet demands during an outage depends on the system demand and the duration of the outage. A reasonable guideline for emergency storage is about one average day's demand, or in the case of CBU, about 20 MG for Year 2030.

CBU currently has about 12.6 MG of system storage excluding clearwell storage at the Monroe WTP and the proposed Southeast tank. Based on 12.6 MG of total system storage, less the previously discussed volumes for Equalization and Fire Storage, the CBU system will have about 10.5 MG of Emergency Storage, or 80 percent of current average day use and about 53 percent of year 2030 average day use.

4. Storage Allocation

It is very unlikely that a maximum hour demand, a 3,500 gpm fire flow, and a major main break and/or a power outage would occur at the same time. Consensus in today's water industry is that it is very conservative and often very expensive to add each storage component together to determine the total required system storage.

In general, system storage should be allocated in terms of position in the storage reservoir. Storage for equalization should occupy the top portion of the reservoir, because equalization storage usually amounts to about one half of the total storage volume within the top 20 feet of the reservoir. Fire storage is positioned next, “under” equalization storage, and emergency storage is at the bottom of the reservoir. The importance of designating levels for types of storage is to ensure that the storage volume has the correct hydraulic grade line for the intended purpose. For example, fire storage may be required at a time when the equalization storage has been depleted. System analysis should ensure that fire storage is available at the hydraulic grade line equal to the “bottom” of fire storage volume allocation. Storage levels would vary from full to depletion-of-equalization volume (or half full) as demand varies throughout the day.

Based on 12.6 MG storage capacity for the CBU system, the following storage allocation can be made for the CBU water distribution system:

Storage	Capacity, MG
Equalization	1.5
Fire	0.6
Emergency	10.5
Total	12.6

As previously discussed, emergency storage requirement is usually a CBU policy issue. The guideline of having one average day use of emergency storage is not a design standard. However, CBU should consider a limited vulnerability assessment to determine the emergency storage requirements.